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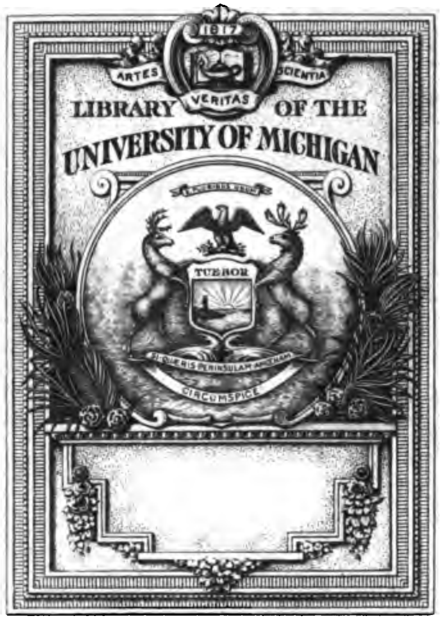

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AN OUTLINE FOR WORK
IN
Experimental Engineering
IN THE
Engineering Department
OF THE
UNIVERSITY OF VIRGINIA

By
JARED S. LAPHAM, M. E.,
ADJUNCT-PROFESSOR OF EXPERIMENTAL ENGINEERING.
UNIVERSITY OF VIRGINIA.

FIRST EDITION

September 1, 1919.

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TO STUDENTS: A SUMMARY OF PRINCIPLES.

Consider that a college education costs you several thousand dollars, which you might earn by devoting the same time to some remunerative occupation—and this regardless of the pocket from which your expenses come. The expenditure will prove an extravagant waste or a money-and-satisfaction-producing investment according to your intention to get the least or the most out of the opportunities purchased by it.

The best value can be obtained from these courses by following the suggestions given below:

(1) Read the references for each group of tests before undertaking the work. They are the standards of scientific and professional practice. When the work is finished, read them again.

(2) Use this laboratory outline as a guide in fitting standard practice to the conditions and equipment of the laboratory. The instructions may be freely modified.

(3) Secure, check and record the items of data in the laboratory with careful accuracy, and with indifference as to how they may affect the final result.

(4) Check every step in the laboratory, and every calculation so that you may be prepared to affirm that the facts presented are *facts.*

(5) Present these facts in a report, designed with engineering skill, to convey information with the minimum of mental friction to the reader.

(6) Buy and use a slide rule and a typewriter. They have become the engineer's indispensable tools.

EXPLANATORY NOTE.

The subject-matter for these courses will be found in the assigned references. The descriptive paragraphs which follow are intended to be supplementary, and are not in themselves either complete or consecutive.

An Outline for Work in Experimental Engineering in the Engineering Department of the University of Virginia

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INTRODUCTION.

THE OBJECT OF ENGINEERING TESTS.

Experimental Engineering can be readily divided into two distinct parts: (1) Tests of engineering materials; (2) tests of engineering equipment. It is not primarily a research subject, but is the outgrowth of research. The majority of the tests have now been standardized either by the American Society for Testing Materials, the American Society of Mechanical Engineers, or by one of the technical branches of the United States Government.

Engineering materials include such building and construction materials as steel, cast iron, cement, stone and timber; fuels and lubricants; and less obviously such substances as water, steam and various gases.

Engineering equipment tests are made on engines of all classes, steam and water turbines, boilers, pumps, blowers, etc., and in general all or any of the apparatus employed in the modern power plant or factory.

Commercial Quality.—All these tests are made for the purpose of securing accurate and indispensable information upon which to base a judgment with regard to commercial quality. Commercial quality does not mean the best in an absolute sense, but all things considered the best to buy for the purpose in hand. For example, the strongest procurable steel would be useless for rivets; and the lowest in objectionable impurities, prohibitively expensive for construction work. It is a mistaken attitude, and one which will lead to disappointment in the laboratory and mortification later, to imagine that commerical quality can be fixed by laboratory investigation alone. For instance, an engine which shows a high efficiency under test may have very little commercial value, if the makers are out of business and repair parts difficult to obtain. On the other hand, experience and judgment are often at fault without the data furnished by experiment. As an example of this, the production of steam is almost always very uneconomical in plants which do not make frequent or continuous tests.

When their limitations are understood, these tests are of great practical value.

LABORATORY PROCEDURE.

Assignment of Tests.—The majority of the tests can not be handled conveniently by one man alone, so the laboratory sections will be grouped into squads of two men or more. When there are more than two men in a squad, the instructor will appoint a squad captain who, in addition to general responsibility for the test, will see that the men move at regular intervals from one duty to another, so that at the end of the test each man may have had experience with everything connected with it. Usually the course will be found to have been divided into two parts. This allows two groups of men to work in the laboratory at the same time. The tests are to be performed in rotation, the squad beginning with the last test progressing to the first, etc.

The date upon which each squad is to perform the separate tests of a course will be posted on an assignment sheet. Study the text references and the brief explanatory note given for each experiment before reporting in the laboratory.

Accuracy is the key-note of this work. The first point to be considered is the accuracy of the testing instruments which are to be used. If these are known to be subject to changes, as is the case with thermometers, spring balances and others, they should be standardized before the main work begins. Scales must always be balanced before weighing with them. In the case of important acceptance tests involving the possible rejection of materials or equipment, every piece of testing apparatus is standardized both before and after the test.

Recording the Data.—With regard to the taking of laboratory data, there is one rule to follow: Record the instrument readings exactly as given on the instrument scale, without mental conversion or computation of any kind. If the zero reading of the instrument is known to be wrong, record the error, and then record the instrument readings. Do not make the subtraction or addition mentally and record only the result. When weighing in a container give gross and tare, not the calculated net, no matter how simple the subtraction.

Rigorously and persistently record exactly what the instrument says, whether it looks likely to lead to a satisfactory result or not. This record is best made on thin sheets with enough carbon paper to give as many copies as will be needed for every man in the squad. Non-mechanical copying of data is an easy way to make mistakes. Always give the units involved. These are exactly as important as the numerical values. More mistakes are made from not knowing or remembering the unit than from any other cause.

No data can be accepted as satisfactory until it has been checked. This usually means that each reading should be taken twice; or that a series of tests where one quantity is made to vary must be shown to follow a consistent law; or in very long single tests, that the separate hours of the run are in agreement. The Bureau of Mines always makes check analyses for every sample of coal tested. As an example of the second case, suppose a test of a steam engine under variable load is being made. Plotting the steam consumption against the load during the progress of the test should give a straight line. For the third case, if making a ten hour boiler test, the efficiencies calculated hourly should substantially agree.

Computation of Results.—Every computation should be checked. One of the most convenient ways is to figure the result with a four-place table of logarithms and check with a slide rule. It must be understood that every numerical statement is only an approximation. The degree of this approximation is to be indicated by the number of significant figures given (0.00237, 237 and 23700 each contain three significant figures). If the results are consistently expressed in three significant figures, the possible numerical uncertainty is much less than the presumable errors in securing the data. A greater number of significant figures in reporting student work is a waste of time and a deceit besides. Very rarely should any engineering computation employ more than four significant figures.

And, finally, cultivate a sense of engineering values. Fix in advance the reasonable limits within which the result must lie. If experience for this is lacking, practice approximate mental calculation, using one significant figure. The approximate product of 1263 and 262 is 300,000, obtained by multiplying the significant figure 'one' of the first number by the significant figure 'two' of the second number, increased to 'three' when the 'six' following is dropped. This method is always valuable in locating decimal points.

ENGINEERING REPORTS.

A series of tests of the same material or machine will be called an 'investigation.' There are a number of separate tests of cement, for instance, which will be considered to constitute an investigation of the qualities of cement. Or tests of the thermal and mechanical efficiencies of a gasoline engine under various load conditions may be taken together as an investigation of the engine's characteristics. Each separate test will occupy one or more laboratory periods. The series of tests will cover several laboratory periods or part of a term.

Preliminary reports, only, will be required for the individual tests. These reports are to be on standard paper, fastened in a folder, and should include the data from the tests, computed results with sample computations in detail, and pencil drawings or curve sheets when these are required.

When the preliminary reports have been checked, the material is in hand for writing a final report covering the investigation. Since the results have been verified and assembled, what remains to be done is to present them in the most useful and intelligible form.

The important principle to follow throughout is this: You have your facts—make it as easy for the reader to get them from your report as you possibly can. With this in view, engineering reports have been standardized in many important details. Follow the standard forms because they have become familiar to the technical reader. An outline, with division headings, for an engineering report is given below.

Object.—The opening paragraph is frequently as far as the reader gets. He wishes to know at the outset whether or not the subject interests him. State as briefly as possible the purpose of the investigation covered by the report. This can frequently be condensed into a single line. For example: "The object of this investigation was to determine some of the important physical properties of concrete-reinforcement bar steel, and their relation to standard specifications." No hint need be given with regard to the results, which will be concisely presented under the Summary.

Equipment.—List the testing apparatus used and identify each piece by giving the maker's name and the serial number. The results of a test are often influenced by peculiarities in the testing apparatus. Important or unusual pieces of apparatus, as well as the machine under test (if it is an equipment test) should be fully described and the descriptions illustrated with sketches. Sketches should be simple cross-sections or diagrams; neither free-hand nor in perspective. They should be on separate sheets. Closely coördinate the sketch with the description by reference to the lettered parts on the sketch. Sketches should be bound directly after the descriptions.

Tables.—Numerical data and results are best presented in tabular form. Standard tabular forms are given for many of the investigations. They should be followed exactly when given. In the absence of such a standard form, give all average values which are necessary for checking the results, or are of interest in themselves. Individual laboratory observations need not be given, unless they are plotted in the shape of a graphical log. Units, of course, must always be given. Precede the decimal point by a cipher in the case of decimal quantities (0.027). Where quantities are in column arrangement, the decimal points should fall under each other even when decimal quantities, taking up space to the right of the decimal point, occur in the same column with large numbers, written to the left of the same point. Economy of space is not the essential, but certainty in the all-important matter of the decimal point's location. When the choice of units is left to the writer's judgment, use the ones most familiar in the case, even when this results in awkward numbers. Tensile strength is invariably expressed in this country in pounds per square inch, although tons per square inch would give more manageable figures. Tons per square inch would be unintelligible to most readers.

Number the items in the table for reference as required below.

Notes to the Tables.—Under this heading treat in separate paragraphs, bearing the item numbers, each item in the Table above which seems to require additional explanation. Omit items already self-evident. Explain the laboratory procedure employed in securing items of data. For instance, if the item is a hook gage reading (in the calibration of weir notches), describe the setting of the hook gage and the special precautions necessary to secure consistent readings. If the item has been calculated from the data, give the fundamental formula employed and the substitution of the proper quantities to obtain the result. Treat this section like the notes sometimes given at the back of Latin texts. Give no explanations for the obvious and familiar, but treat fully everything that is new and apt to present difficulties.

Curve Sheets.—If the load on a bar of steel varies, how does the stretch vary? If the head against which a centrifugal pump operates should increase, what would happen to the rate of delivery? Experimental investigation is largely made up of questions of this kind. In all such cases, the two variables should be plotted on coördinate axes, points of intersection located and marked, and a curve or line drawn to show their relationship.

The most important point in drawing the curve sheet is in the selection of the scales. Make the main divisions of the curve sheet correspond to one, two, or five units (or some decimal multiple or submultiple thereof) of the scale selected. The employment of any other scale for the sake of fitting the dimensions of the curve more perfectly to the size of the paper results in difficulties in plotting and awkwardness in reading from the curve afterward.

The independent variable (that is, the one under the experimenter's control, like the load in an engine test) with one important exception, is always used for the horizontal axis of the paper. This exception is in the case of stress-strain diagrams in testing materials, in which convention has reversed the usual arrangement, and the stress, which the operator may vary, is here plotted on the vertical axis.

Select a horizontal scale under the restrictions given that will extend the curve as nearly across the paper as possible.

The success of the curve sheet depends upon the selection of the proper vertical scale. If too open a scale is used, the plotted points will fall all over the paper, and it will be impossible to draw a smooth curve or line among them to establish the graphical average of their positions. If the scale, on the other hand, is too close, all points will fall on a horizontal line, and the purpose of the work will have been defeated, since all the variations have been ironed out by the minuteness of the scale chosen.

In addition to the curve itself, the curve sheet must give whatever information is required to completely and readily understand it, without reference to the body of the report. This information can be put in vacant spaces, and of course should not be written over the curve or in the area occupied by the points. If you have plotted the characteristic curve for a blower, this should be the title, and the size, type, speed, etc., should also be given.

Use a bow-pen or bow-pencil to plot the points. Do not make them more than one-sixteenth of an inch in diameter. Do not draw the curve across the clear area within the small circles, but break it at the circumference. Give the quantity and unit on the margin of each scale. Mark the scale graduations throughout the length used.

Summary of Results.—As the object defined the purpose and scope of the investigation, the summary should give briefly its results. In practice these two paragraphs are frequently all that will be read. Give your important numerical results briefly; back them up by one or two quotations from similar tests in print, with text and page in case verification should be desired; and give your personal conclusions and interpretations, referring specially to the curve sheets.

Number the pages. The use of the typewriter is strongly recommended.

CHAPTER I.

ROAD MATERIALS TESTING.

A typical macadam road is built of crushed stone, and may be bound with asphalt or tar to prevent rapid disintegration in service. Stone, asphalt and tar are therefore the mateials to be tested.

Description of the Materials.—Rock is a mixture of minerals in which metallic silicates usually predominate. 'Igneous' rock has been fused and afterward cooled at a rate sufficiently slow to permit the formation of crystals. If the rate of cooling is very slow, the crystals are visible to the eye, as in the case of granite. But if the cooling is more rapid, the crystals are fine or microscopic. 'Trap' is a general name applied to a number of rocks belonging in this class. Very rapid cooling would usually result in a partially crystalline lava, or a non-crystalline glass.

Weathering may disintegrate an igneous rock. If the disintegrated particles are later deposited and recompacted under pressure into a new stone, the rock is said to be 'sedimentary.' For instance, the hard particles of silica set free by the decomposition of a granite, may be reunited into a sandstone.

A 'metamorphic' rock may be produced by either heat or pressure, acting over long periods, from an igneous or a sedimentary rock. The evidence of metamorphism lies in a change in physical structure. Gneiss is a laminated granite, while quartzite is a very fine grained, compact sandstone.

Non-crystalline limestone and its metamorphic product, crystalline marble, are principally composed of calcium carbonate, believed to be of organic origin.

Asphalt is a petroleum product. It is the residue after distilling gasoline, kerosene, lubricating oils, etc., from the petroleums of the western or mid-continent oil fields, (the eastern fields give paraffin instead of asphalt as their final distillation product). It is also found in native deposits.

Tar is a by-product in the distillation of coal gas. When the gas cools from retort temperature to room temperature, it is partly liquified, partly solidified, the remainder passing on as a gas. Tar is the semi-fluid mixture of these liquids and solids, with a large percentage of added soot.

Description of the Tests.—The tests for stone are intended to duplicate as nearly as possible service conditions, and indicate quite closely the value of the stone for a macadam road. The specific gravity test is included in all tests of materials, and is for the purpose of identification only; the absorption test shows the amount of water taken up internally by the stone, and indicates the probability of disintegration by frost; the cementing value test shows the ability of the stone to bind itself into a durable road surface, with the addition of water only, and has no value when tar or asphalt are to be used; toughness shows the strength of the stone under impact; resistance to abrasion, the expected wearing qualities; and the compression test, the force required to crush it under load.

The tests for tars and asphalts illustrate another method of using laboratory results. The qualities which make a satisfactory road binder are not clearly understood, but the physical properties of a road binder which has proved successful in service may be found by test. Then when a similar material has similar physical qualities as shown by test, it will usually give similar results in service.

ENGRG. 650—ROAD MATERIALS TESTING.

(A) An Investigation of the Physical Properties of Stone for Road Building. (References).

1. Specific Gravity.
2. Absorption.
3. Cementing Value.
4. Toughness.
5. Resistance to Abrasion.
6. Compressive Strength.

(U. S. Dept. of Agri., Bulletin No. 347.)

(B) An Investigation of the Physical Properties of Asphalts and Tars.

1. Specific Gravity.
2. Penetration.
3. Melting Point.
4. Volatilization.
5. Viscosity by Float.
6. Fixed Carbon.

(U. S. Dept. of Agri., Bulletin No. 314.)

Note.—The above bulletins may be obtained free of charge by addressing the Office of Public Roads and Rural Engineering, Washington, D. C.

Notes to the Tests.—Test a sample of sandstone from the University quarry, and a second sample selected for its suitability as a road material. Compare and comment on the results.

(A4) The preparation of the cores for the toughness and compression tests offers some special difficulties. The specimen should be bedded on a sand bag. Feed plenty of water to the drill and press very lightly, or the diamond points will be destroyed.

New saws for cutting off the cores will not take hold within the first hour of continuous use. Never attempt to break them in with a file.

(A6) Face the cores off as smoothly and as nearly at right-angles to the axes as possible. When testing, bed the ends with small pieces of beaver-board.

(B) Test two samples of tar and two of asphalt, making duplicate determinations for each test.

CHAPTER II.

STRUCTURAL MATERIALS TESTING.

The tests, as shown in the table following, have been grouped into two investigations. As usual, a formal written report will be required for each investigation.

Portland Cement.—One of the oldest of engineering processes is the production of common lime by burning limestone in a kiln at a bright-red heat. If there is some clay mixed with the limestone, the resulting lime makes a superior, water-resisting mortar. And, further, if approximately one-fifth of the mixture is clay, and the burning temperature is raised to a point just short of fusion, a clinker is obtained which, when ground, is Portland cement.

Cast Iron is made by de-oxidizing iron ore in a blast furnace. The ore (an oxide of iron) is charged into the top of the blast furnace stack, with the proper additions of coke and limestone. The coke effects the chemical reduction of the ore, at the same time supplying the necessary heat by its combustion, and the lime, mixing with the clay and sand brought in with the ore, makes the slag fluid. Hot air blows continuously through the charge. The iron takes up large percentages of carbon from the coke.

Steel.—The process of making steel from cast iron consists in reducing the three or four per cent of carbon in the cast iron to between one-tenth of one per cent and one per cent and a half, depending upon how hard the metal is to be. This range includes all steels from the softest rivet steel to the hardest varieties used for metal-cutting saws. Structural steel has about one-quarter of one per cent of carbon, with all other impurities reduced to a minimum.

In the Bessemer process, the decarbonizing of the cast iron is effected by blowing air through the liquid cast iron, which is contained in a pear-shaped vessel called a Bessemer converter.

The oxidizing of the carbon in the open-hearth process is due to the flame of producer gas which burns above the surface of the liquid cast iron in the reverberatory open-hearth furnace.

Structural Timber.—The important structural timber is the yellow pine of the South. Hard woods are both scarce and difficult to work.

Tests of Cement, Sand and Concrete.—The American Society for Testing Materials, which is an association of manufacturers and consumers of engineering materials, has standardized the tests for Portland cement sold under its specifications. These specifications have fixed the qualities of a cement which is satisfactory in service, and not unreasonably expensive to manufacture. It is to be noted, therefore, that the following tests which include those specified with some additions, do not undertake to grade a cement, but to decide whether the cement meets the requirements which both the manufacturer and the user have found to be satisfactory and sufficient.

The fineness test shows the thoroughness of grinding, upon which strength depends; the soundness test indicates whether the cement will show changes of shape and consequent cracks with time; the consistency test gives the correct mixture for the strength test specimens; and the tensile test establishes indirectly the compressive strength, the most important item. The tensile test is more frequently made than the compressive test because, since the strength in compression is usually about ten times the strength in tension, not so large a machine is required. These last two tests may be made with pure (neat) cement, but are ordinarily made on mortar mixed from standard sand.

The suitability of any other sand for mortar or concrete is found by comparing the strength of its mortar with the mortar made from standard sand, using the same cement.

Screen analyses of sand, gravel, or crushed stone show the relative proportions of different sized particles, and give the necessary information for mixing to secure the greatest density and hence strength for concrete.

Tests of Metals and Timber.—Specifications for metals are written either in terms of physical or chemical tests. Both physical and chemical properties, of course, must not be specified. For construction purposes, physical tests are usually specified, but machinery steel is frequently bought on the basis of chemical analysis, alone.

The important physical tests are the following: (1) The maximum load unit area (based on measurements previous to loading) will carry under the method of loading to be followed in service. Sometimes a different method of loading is used in the testing, as in the case of cast iron, which is tested as a beam, and usually loaded in compression. This is again, as in the case of cement, because a much smaller machine may be used for the transverse test than for the compression test.

(2) The elastic limit, which is well below the maximum load and represents the point beyond which the load must not be carried if perfect recovery is to take place. This can only be located accurately by measuring the deformations and plotting the stress-strain diagram. In commercial laboratories, where quick results are demanded, it is determined approximately for steel by noting the load when the scale beam drops with the sudden sag of overstrained material. This value is higher than the true elastic limit, and is called the 'yield point.'

(3) The modulus of elasticity below the elastic limit, which shows the metal's stiffness. This can only be satisfactorily found from the stresss-strain sheet.

(4) The amount of distortion at rupture, or under a given load beyond the elastic limit, which shows the metal's toughness, or the total work necessary to break down its resistance.

For rapid work in commercial testing, the autographic attachment to the testing machine is invaluable.

Physical tests are not specified for timber because visible dedefects, such as knots, checks, etc., settle the question of strength better than laboratory tests of small, clear specimens. The two tests given are research exercises.

ENGRG. 660—STRUCTURAL MATERIALS TESTING.

(A) An Investigation of the Physical Properties of Cement, Sand, and Concrete.

	(References.)
*1. Soundness and Tensile Strength.	C&D 1-6; 13-20.
2. Compression Test for Cement.	ASTM (C9-17).
3. Compression Test for Concrete.	
4. Tests of Sand.	C&D 61.
*5. Consistency and Set.	
*6. Fineness.	
*7. Specific Gravity.	
8. Mechanical Analyses.	Baker 302-309.
9. Determination of Voids.	Baker 193-198.

(B) An Investigation of the Physical Properties of Metals and Timber.

*1. Tensile Test of Wire.	C&D 39-42. C&D 48-53.
*2. Modulus of Elasticity.	C&D 55-57; 59. C&D 62-63.
3. Calibration of Testing Machines.	
*4. Standard Tensile Test.	ASTM (A15-14).
*5. Standard Compression Test.	C&D 43; 70-71. C&D 65.
*6. Torsion Test.	C&D 46; 75-76.
*7. Transverse Tests (mid-point).	C&D 44; 72-74.
8. Transverse Test (trisection)	ASTM (A48-18).
9. Autographic Testing.	C&D 64.

Note.—C&D = Carpenter & Diederich's Experimental Engineering, 1915 edition.

ASTM = Standards of the American Society for Testing Materials.

Numerals refer to articles, inclusive, or to standards.

Tests (*), only, are to be given for the shorter course, Engrg. 661, Structural Materials Testing.

Notes to the Tests.—It will be necessary to test only one cement, a standard brand of Portland cement procurable in the local market. Perform the tensile test, however, on both neat cement and cement mortar.

(A1) The total weight of the mix, exclusive of water, should be about 1500 grams for each batch. The standard sand is to be screened to pass a number twenty and be retained on a number thirty screen. Smear the moulds with a thin coating of kerosene before putting in the cement or mortar. The most important point is to fill the moulds evenly. Add an excess of material and draw the trowel across the surface, exerting a moderate pressure. Turn the moulds over and repeat. Weigh the test specimens before testing, and reject those varying more than three per cent from the average.

Make the pats for the soundness test from the batch of neat cement. Ask the instructor for the proper water percentage to use in mixing the neat cement, if you have not performed the consistency test.

(A2) Make sand mortar specimens in the small cylindrical moulds. These are to be tested at the end of twenty-eight days with the large Olsen machine arranged for compression. Bed the ends with squares of beaver-board.

(A3) Fill the large cylindrical moulds with concrete mixed from ordinary sand and crushed stone. Trowel carefully down the sides of the mould from each end to work the water and fine materials to the surface of the moulds. Moulds are to be covered with damp cloths for two days. Then remove the specimens from the moulds and put under water in the moist closet. Test at the end of twenty-eight days, using the Olsen machine as in (A2).

(A4) Exactly similar to the tensile test for cement mortar, except that ordinary sand is to be used instead of standard sand.

(A5) Mix a fresh batch for every consistency test, varying the amount of water in such a way as to give about six tests covering the whole range of consistency. As soon as the normal consistency has been approximately determined, fill the extra ring and place it in the moist closet. Test at ten minute intervals with the needle and the corresponding cap. When the initial set has taken place, remove from the ring and observe at intervals of one hour for hard set.

(A6) Screen through a twenty-mesh screen to remove lumps and trash. Do not put coins or shot in the sieves, which seriously injure the mesh. Continue sieving until less than one-tenth of one per cent of the original weight passes the sieve, by test, in one minute of continuous sifting. Make check tests. Do not be satisfied until these agree within one per cent.

(A7) The success of this test depends upon the care and slowness with which the cement is introduced into the flask. Make duplicate trials, which should agree within 0.01. Rinse the flask with kerosene and never with water. Do not empty the flask into the sink.

(A8) Make a sieve analysis of the sand and stone used for the concrete specimens. Plot the ideal parabolic curve for the mixture, and the sieve analysis curves for both materials. Calculate the best mixing proportions, and plot the combined curve corresponding to these proportions.

(A9) Determine the proportion of voids for both sand and stone samples.

(B1) Test four representative wires, check tests on each. Balance the machine. Measure the diameter of the specimen to the nearest 0.001 inch. If the extensometer is set to zero, with the extension pushed in, it clamps a length of eight inches. See that the set screw on the extension is tight, and the set screw on the vernier loose. The extensometer should be removed just before the wire breaks. Report ultimate strength, and elastic limit. Use 500 lb. load increments, beginning with this as the initial load.

(B2) Modulus of elasticity tests are to be made on the four rods, steel, wrought iron, brass and German silver furnished with the Ewing machine. Look up the ultimate strength of these materials, and calculate a maximum load for each rod not over one-quarter of the ultimate strength. Take for the initial load and the load increments one-tenth of the maximum load. Take readings with the Ewing extensometer for increasing and decreasing loads. Handle the extensometer with great care. Plot the results and figure the moduli from the slopes of the straight lines. This method is always more accurate than arithmetical calculation, since it gives the graphical average. Note that the lines start from the neighborhood of the initial loads and not from the origin of coördinates. The object of the initial load is to take up unavoidable slack in the testing machine and grips.

(B3) Place the calibrating levers in position, and hang the trays on them. Balance the machine approximately with a small weight fastened by a wire to the end of the beam. Balance accurately with adjustable counterweight. Record machine readings for increasing and decreasing loads at intervals of 1000 lb. Be careful to have the trays equally loaded, or the machine may be upset.

Examine the driving gears and find for a driving speed of 200 r. p. m. the speed of the pulling heads (using slowest drive combination) in inches per minute. Sketch either machine.

(B4) Test a specimen cut from a concrete-reinforcement bar corresponding to the specifications ASTM (A15-14).

Assume the elastic limit to be 30,000 lb. and calculate increments of load that will give about 10 readings to the elastic limit. Make one of these the initial load. Remember that this and all other weighing machines must be balanced by adjusting the counterpoise before beginning a test. See that the check nuts rest loosely on the table. The test piece must be gripped in the jaws a distance sufficient to prevent their spreading when the load is applied. Use the slowest speed of the machine (the hand-wheel). After applying the initial load, attach the extensometer, being careful to have it accurately centered.

The extensometer is to be read as follows: First back off both screws; then bring forward the left-hand screw until the bell rings; back it off very slowly, one division at a time, until the bell stops ringing; read and record; then back it off still further and manipulate the other screw in the same way.

Remove the extensometer at the yield point, and measure extensions with calipers and scale at several points prior to rupture. Make one of these points the maximum load. After rupture, measure the total extension (to be recorded opposite load at rupture) and the contracted diameter.

Plot stresses as ordinates and strains as abscissas, and average the position of the points with a curve which will be straight to the elastic limit. Replot this section of the curve on the same sheet using the same stress scale and a strain scale such that the slope of the straight line will be about 60°. Compute from this slope the modulus of elasticity. Calculate the reduction of area and ultimate extensions as per cents. Record the elastic limit, the yield point, and the tensile strength.

(B5) The steel tested is the same as in (B4). Mark with two light punch marks a distance of two inches on the surface of the specimen, parallel to its axis. Place the sharp-pointed set screw of each ring in one of the punch holes. Adjust the set screws so that the rings are central and their planes perpendicular to the axis. Place the specimen exactly at the center of the compression blocks. Place the compressometer in position, with its fingers resting on the inside surfaces of the rings. Read compressometer by adjusting downward until bell rings. Then adjust upward, passing over one scale division at a time until the bell stops ringing.

Assume the elastic limit to be about 30,000 lb. per sq. in. and calculate increments of load to give about ten readings to the elastic limit.

At yield point, remove the compressometer and loosen rings. Measure compression with calipers and scale 5000 lb. intervals until specimen is very sensibly distorted.

Plot stresses as ordinates and strains as abscissas, and average position of the points with a curve, which will be straight to the elastic limit. Replot this section of the curve on the same sheet, using the same stress scale, and a strain scale such that the slope of the line is about 60°. Compute from this slope the modulus of elasticity. Record on the curve sheet the elastic limit, and the yield point.

(B6) The steel tested is the same as in (B4) and (B5). Balance the machine. Mark a length of eight inches parallel to the axis of the specimen with two light punch marks. Mark a light line with a scribe parallel to the axis of the specimen and from end to end. Put on the two pointers and fasten the specimen in the machine by carefully centering it in the chucks—but do not set them tight. Apply an initial load of 25 lb. ft. and tighten chucks moderately.

Fasten the pointers at the extremities of the length previously marked. Measure equal distances upon the pointers from the axis of the specimen. Since this distance must be the radius of the circular scales, it is to be first calculated from the length and height of the arcs. Adjust the circular scales to the marks on the pointers, and adjust the pointers to the zero of the scales.

When the end of one of the circular scales is reached, loosen both pointers and continue loading until the specimen breaks. Record in table the final load and the angular twist, which is to be found from the number of rotations of the scribed line in the marked length of eight inches.

Plot shearing stresses as ordinates and shear angles as abscissas. Draw the average curve, which will be straight to the elastic limit. Replot this section of the curve on the same sheet, using the same scale for shearing stress, but selecting a new scale for shear angle, such that the slope of the straight line will be about 60°. Calculate the modulus of rigidity from this slope. Record on the curve sheet the elastic limit, the yield point, and the shearing strength.

(B7) Test duplicate samples of the arbitration bar for cast iron, and three specimens of typical timber. Calculate the probable load at the elastic limit in each case, and take one-tenth of it for the initial load and the load increments. Protect the wood from injury by the knife-edges with thin metal plates. The span for the timber specimens is 20 inches. Test to rupture. Plot stress-strain curves for all tests.

(B8) Use the lathe-bed apparatus, with scale and thread. Test three specimens of wood. Assume the elastic limit to be 4000 lb. per sq. in. and calculate increments of load to make about ten readings to one-half the elastic limit—and do not carry loading above this value.

Mark a length of 60 inches on the specimen. Mark the midpoint and the trisection points. Attach a scale reading to tenths of an inch, with its edge on center mark. Fasten a thread in the line of the neutral fiber—It is to be kept stretched by means of a weight suspended from one end. Fasten one end of thread and allow the other to pass freely over a smooth nail. Estimate tenths of a scale division read against the thread, which must pass close to, but not be in contact with, the scale.

Protect the wood from injury by the central knife-edges by means of thin metal plates.

In adding weights, be careful not to change the point of application of the load. Include in the initial load the weight of the hangers.

Plot stresses as ordinates and strains as abscissas and average the position of the points with straight lines. Calculate the moduli of elasticity from the slopes of the lines.

(B9) Use the Riehle autographic apparatus. Test a sample of steel in tension, and a sample of wood in compression.

Prepare the wood specimen by sawing four-inches from the end of one of the transverse specimens, using a mitre saw for the purpose. In the compression test, use metal plates above and below the specimen, and set one of the standard fifty pound weights on top of the movable head to bring the level up to the autographic fingers. Square the ends of the specimen with an initial load of 5000 lb. Release and start the test.

In tensile and compression tests use slowest speed to the elastic limit—then change quickly to the next higher speed.

The speed of the poise should be adjusted with wheel until its motion is nearly continuous and the beam hangs steady.

To avoid running down batteries, see that they are disconnected when not in use.

Give a complete description of the autographic apparatus, illustrated with sketches, and a diagram of the electric wiring. Submit an autographic card from the test. Both tests may be shown on the same card by spacing them horizontally one-tenth of an inch apart. (For further explanation, see Riehle and Olsen catalogs).

CHAPTER III.

FUEL AND OIL TESTING.

Coal is vegetable matter, deposited in previous geologic ages, and partially devolatilized by pressure and heat. As delivered for consumption, it is composed of six principal ingredients: (1) Superficial moisture, which a current of warm air will remove. (2) Inherent moisture, which can be expelled by heating the coal at a temperature above the boiling point of water. (3) Volatile matter, the gas of coal, driven off at a white heat. (4) Fixed carbon, the combustile material or coke remaining after the expulsion of the coal gas. (5) Mineral matter or ash, either originally laid down with the coal, or included in the process of mining. (6) Small amounts of sulphur. Coal is classified into ranks, depending upon the extent of devolatilization, the highest rank coal having the smallest percentage of volatile matter. These ranks, starting with the highest, are anthracite, semianthracite, semibituminous (a misnomer for a rank which should be called superbituminous), bituminous, subbituminous, and lignite, the last approaching peat and least changed from the original wood. High volatile matter is usually associated with high moisture as in subbituminous coal, and such coal is smoky and low in heating value. But since the volatile matter has a higher heating value than the fixed carbon, the best steam-making coal is reached in semibituminous, which has a higher heat value than either bituminous or anthracite. It produces more smoke than the nearly smokeless anthracite, but less smoke than bituminous coal. Anthracite and semianthracite, on account of their smokeless qualities reserved for the domestic fuel market, except in the very small sizes. Semibituminous is limited in quantity. Bituminous coal, high in volatile matter and heating value, and requiring great care in combustion to avoid excessive smoke, is the principal steam coal.

Occurrence of Coal.—Coal occurs over definite areas in superposed, stratified beds. The majority of coal mines in this country are drift mines, working the outcrop of these beds. The greatest of these coal areas is in the Appalachian trough, extending southward from Pennsylvania and Ohio, through West Virginia, Virginia, Kentucky and Tennessee to Alabama. Geologic action has exerted its greatest pressure on the eastern side, and the coal, generally speaking, decreases in rank from east to west, and the coals of lowest volatile matter and highest rank are found on the eastern edge. The only commercially important anthracite fields are near Scranton, at the extreme eastern limit of the area. Through Pennsylvania, Maryland and West Virginia (the Pocahontas and New River fields) there lies a tenderloin-like strip of semibituminous coal against the main area of bituminous coal extending westward.

East of the Mississippi River, the only other field of importance is the eastern-interior province, extending over parts of Illinois, Indiana, and western Kentucky. In comparison, the coal of these regions is high in ash and volatile matter, and low in heating value. It is generally inferior in steam-making qualities to the bituminous coal of the Appalachian region, even to the bituminous coal of Ohio, which is of a lower grade than that from Pennsylvania and West Virginia. It is free-burning, however, not caking like eastern coal.

West of the Mississippi, much of the coal mined is subbituminous and lignite.

Lubricating Oil is a middle-distillation product, from crude petroleum, in a series beginning with the lightest gasoline and ending with paraffine or asphalt. In some cases, it is the residue after the lighter products have been distilled off. It may be thickened by the addition of tallow or mineral soap.

Coal Tests.—Upon the sampling of coal, depends the whole value of the tests which follow. Not less than a quarter of a ton should ever be taken for the original sample before reduction. The proximate analysis determines the total moisture, volatile matter and ash, fixes the rank of the coal and its suitability for any particular furnace and stoker installation. For example, high ash, free-burning coal does well on a chain-grate stoker, because the ash protects the grate, and the open fuel bed does not require the agitation which this type of stoker can not supply. Moderately low-ash coal is almost necessary for underfeed stokers, which throw the ash to the top of the fire, with consequent fusion and clinker trouble.

The heating value test gives the theoretical number of heat units (a thousand heat units will roughly evaporate one pound of water) which can be obtained by the combustion of one pound of coal; and, in connection with the proximate analysis and such other items as price, delivery, etc., fixes the desirability of the coal as a fuel.

Gas Calorimetry, or the determination of heating value, is similar in theory to that for coal. If the gas tested is from the laboratory mains, it is coal gas, distilled in closed retorts from bituminous coal rich in volatile matter.

Tests of Lubricants.—Lubricants are designed to float apart rubbing surfaces, and to substitute for dry, solid friction their own internal viscosity. Direct tests of friction, under lubrication, of which an example is given, are not generally satisfactory. The best lubricant is usually the one with the lowest viscosity which will safely float the moving surface; or, in the case of cylinder lubrication, seal the piston. Hence the importance of the viscosity test. The flash test is made in the interest of safety in storage. An oil with a low flash test will give off inflamable vapour, with the possibility of fire or explosion. The specific gravity, as usual, helps to identify the oil. Chill tests are made on oils to be used in exposed locations in winter, and show the minimum temperature at which they will remain fluid.

ENGRG. 670—FUEL AND OIL TESTING.

(A) An Investigation of the Physical Properties of Lubricating Oil.

	(References).
*1. Viscosity.	C&D 112; 117-118 125; 141.
*2. Flash and Burning Points.	C&D 129-132.
*3. Coefficient of Friction.	C&D 134-135.
*4. Specific Gravity by Hydrometer.	C&D 123-124.
*5. Specific Gravity by Pycnometer.	
*6. Chill Point.	C&D 127-128.

(B) An Investigation of the Properties of Fuels.

1. Sampling Coal.	ASTM (D21-16).
2. Proximate Analysis of Coal.	C&D 265-269.
3. Standardization of Calorimeter.	B of S Cir. 11.
4. Heating Value of Coal.	C&D 254-256. B of M Tech. Pap. 8.
5. Sling Psychrometer.	C&D 410.
6. Gas Calorimetry.	C&D 261.

Note.—C&D refers to Carpenter & Diederich's Experimental Engineering, 1915 edition; ASTM is the Standards of the American Society for Testing Materials; and 'B of S' means the Bureau of Standards, Washington, D. C., whose publications may be obtained free of charge upon request. 'B of M' refers to the Bureau of Mines, Washington, D. C.

Individual copies of the standard may be had at a cost of 25 cents, each, by addressing the Secretary, University of Pennsylvania, Philadelphia, Pa. Numerals applied to articles are inclusive.

Tests (*) are to be given for Engrg. 671—Fuel and Oil Testing.

Notes to the Tests.—(A1) Use Engler viscosimeter. Test a sample of steam-cylinder oil, gas-engine oil, and turbine oil in 10°F steps from 80°F to 200°F. Viscosity is defined to be the ratio between the time of flow of a quantity of oil, and the time of flow of an equal quantity of water. Hence, first standardize the instrument by finding the time of flow of 200 cc. of water at temperatures ranging from 80°F to 200°F. Take the mean.

Before standardizing the instrument, clean carefully, particularly the discharge orifice. Fill the outside vessel with lard oil. Fill the inside cup with water until the three leveling points just puncture the surface. Heat the outside bath until its thermometer gives the desired reading; then heat very slowly until the thermometer in the cup reads the same. Keep bath and cup well stirred. Take the temperature of the water in the cup, the time, and open the orifice by raising the rod. Allow 200 cc. to run through, and take temperature and time again.

Replace the water in the cup with oil, and follow the same procedure.

The viscosity so determined is a ratio, which is called the Engler number. Plot the Engler numbers as ordinates, and the temperature as abscissas, and draw viscosity curves. Make a sketch of the viscosimeter.

(A2) Use the New York State Board of Health (the Elliott) tester. Test the same series of oils as in (A1). The temperature must not be raised faster than five degrees Fahrenheit per minute. Test every two degrees.

Remove the oil cup and fill the bath with lard oil. Fill the oil cup to within three millimeters of the flange joining the cup and the vapour chamber above. Put on the glass cover and lower thermometer until its bulb is just covered by the oil.

Adjust testing flame to a length of five millimeters from the tip of the capillary tube. The last reading of the thermometer before an instantaneous blue flame spreads over the surface the oil is the flash point.

Remove the glass cover and continue testing as before until the surface of the oil takes fire and burns. The last reading of the thermometer before this occurs is the burning point.

Put out the flame by covering the cup with a piece of metal. Do not, under any circumstances, attempt to blow out the flame. Watch the test carefully when the temperature reaches and passes the boiling point of water, as water in the oil will make it spatter.

(A3) Start the machine running light, and increase normal load by 250 lb. Increments at 15 min. intervals. Take readings every two minutes. Test the same oils as in (A1).

Study the construction and operation of the machine. Calibrate the weighing device. See that the adjustments are all correctly made. Measure the projected area of the bearing box. Calibrate the oil feed at 10 drops per minute for each of the three oils. Make a preliminary run.

Before changing from one oil to another, the box, journal, and feed cup must be thoroughly cleaned with gasoline.

Plot coefficients of friction as ordinates (mean value), and normal pressures (pounds per square inch of projected area as abscissas. Also temperature (means) as ordinates. Find the mean velocity of the rubbing surfaces.

(A4) Use the oils specified in (A1). Find their specific gravity, and also the specific gravity of the gasoline and kerosene in the use in the laboratory. When testing with the hydrometer, the temperature of the oil should be as near to 60°F as is conveniently possible. Sink the hydrometer into the oil slowly, so that it will not fall below its equilibrium point. Attempt to read the intersection of the liquid plane with the scale stem.

(A5) Repeat (A4), using the pycnometer method, and compare the results with those obtained with the hydrometer. Which is the more accurate?

(A6) Use the same oils as in (A1). Mix the salt and ice. Put a small sample of each oil in the bottom of a test tube and freeze them. Stir the samples with a thermometer until they are warm enough to flow the whole length of the test tubes. The temperatures then noted are the chill points.

(B1) Follow closely the standard method of the American Society for Testing Materials. Sample the coal in stock at the University power plant.

(B2) Grind the reduced sample in the coal grinder to pass a 60-mesh screen. Test a one-gram sample in a porcelain crucible for total moisture by heating for one hour in the jacketed drying oven. The jacket of this oven must be filled nearly full with a mixture of water and glycerin in order to raise the drying temperature of 220°F. After drying, transfer the sample to the gas-muffle furnace, and burn out the combustile to determine the ash. Weigh out another one-gram sample in a platinum crucible, cover it, and heat for seven minutes over the flame of a standard bunsen burner. The flame of the burner should be seven inches high, and the crucible three inches above the top of the burner tube. Make a check analysis.

(B3) The calorimeter is standardized by burning a sample of napthalene of known calorific power in place of the coal. With the result obtained for the temperature rise, the water equivalent of the calorimeter can be calculated. For the method of operation, see (B4), below.

(B4) Weigh with an accuracy of one milligram the fuel charge, which should be approximately 0.6 gram. If the fuel is napthalene, it must be made into a briquette. This is placed in the pan and the firing wire connected and let touch the fuel in the pan. Be careful not to ground the firing wire. The upper half of the bomb is placed in position, and the nut screwed down as far as may be by hand. Be very careful not to cross the threads. The shoulder on the upper half of the bomb must be lubricated, but do not allow any oil to get on the lead gasket.

In charging the bomb with oxygen, open the spindle valve on the bomb one turn, and then open the valve on the supply tank very cautiously. When the pressure reaches 300 lb., close the supply valve, and then the valve on the bomb.

Weigh approximately 1900 grams of water and put it into the calorimeter can, and then immerse the bomb in the water in the can. The temperature of the calorimeter water should be about 1°C below the temperature of the jacket water. The temperature of the jacket water should be, ordinarily, the temperature of the room. The bomb must not touch the sides of the can, and neither stirrer nor thermometer must touch the bomb.

Take temperature readings at one minute intervals for five minutes, fire the bomb, and take half-minute readings until the maximum temperature is reached. Then continue reading temperatures at one minute intervals for five minutes more.

Give a simple sketch of the calorimeter, and a temperature curve for the run, temperatures as ordinates, and time in minutes as abscissas.

(B5) The evaporation from a wet surface depends upon the vapour content of the air. Wet the gauze surrounding one of the two identical bulbs of the sling psychrometer. Swing the instrument rapidly until the minimum readings are reached. The humidity can be found from the table given in the reference.

(B6) Make duplicate tests on a sample of city gas as supplied to the laboratory. Regulate the cold and hot-water valves, and fill the horizontal supply tank with water at the desired temperature for the test.

Report both high and low heating values, and the gas pressure.

CHAPTER IV.

HYDRAULIC TESTING.

Bernoulli's Theorem.—If the elevation of the reservoir is known, what will be the velocity of flow through a given size of city main? Under a given pressure, what will be the velocity of a jet of water from a turbine nozzle? What pressure must be carried in the service mains to insure a specified height for the stream from a fire hose? These are problems in the relation between pressure, gravity head, and velocity for a stream of flowing water.

Elementary hydraulics differs from most subjects, because it is limited to a single fundamental idea. This fundamental and controlling idea is Bernoulli's Principle, and nearly all the problems presented owe their solution to it.

Bernoulli's Principle is an application of the Law of the Conservation of Energy to steady stream-line flow. The conservation of energy requires that the total energy of any particle of fluid must remain unchanged as it proceeds with the stream. Bernoulli's Principle fixes the kinds of energy that such a stream particle may have, and defines them in mathematical terms. Students of elementary mechanics are familiar with the notions of kinetic energy, or the energy resulting from velocity of motion; with potential energy produced on every particle of matter by virtue of its position in the field of gravity; and with the fact that they are mutually convertible, as when a body falls from rest and secures velocity in exchange for elevation. Bernoulli's Principle adds to this pair a third form of energy, the energy of stream pressure; states that the total of the three must remain constant throughout the stream; and that each may be converted into either or both of the remaining two.

Since potential energy is the head, the kinetic energy is expressed in terms of the velocity, and the pressure energy in terms of the stream pressure, this principle furnishes an equation connecting head, pressure and velocity.

The stream-pressure energy belongs to the particle, because the particle belongs to the stream. It is not the energy stored by compression in the particle, as might naturally be supposed for fluids are not sensibly compressible, and therefore can not have this kind of energy. Even in the case of a flowing, compressible gas, the energy of compression still lacks the conversion privilege, and the expressions for gas flow and liquid flow are the same.

Description of the Experiments.—With the exception of the pump tests, these brief exercises are intended to establish by test the terms and coefficients necessary to fit Bernoulli's Principle to practical working conditions: not because the theory is defective, but because actual conditions are never the simple ones necessarily assumed in theory. Standard orifices, weirs, and the Venturi meter, after this process of calibration, become the most reliable types of water meters. The establishment of the additional term in the theory required to account for friction is the subject of the experiment on friction in pipe flow. Curiously, the coefficient found may be approximately applied to many different kinds of liquid and gaseous flow, from the retarding effect of stacks on chimney gases to the power required to pump oil through a pipe line.

The tests of the pump are the standard ones, and are made principally to determine its efficiency, or the cost of operation; its power, or the maximum expected output; and the slip, or the amount of leakage.

ENGRG. 680—HYDRAULIC TESTING.

(A) An Investigation of Stream Flow. (References.)
- 1. Calibration of Standard Orifices C&D 190-193.
  - a. Horizontal.
  - b. Vertical.
- 2. Calibration of Standard Weirs. C&D 196-200.
  - a. Rectangular.
  - b. Triangular.
- 3. Friction in Pipe Flow. C&D 218.
  - a. Straight Pipe.
  - b. Pipe Elbows.
- 4. Calibration of Water Meters.
  - a. Venturi Meter. C&D 195.
  - b. Oscillating Piston Meter. C&D 203-205.

(B) An Investigation of a Piston Pump.
- 1. Separating Calorimeter. C&D 309-312.
- 2. Pump-valve Setting.
- 3. Pump Tests. ASME 87-99.
  - a. Steam Consumption at Fixed Speed and Variable Pressure.
  - b. Delivery at Fixed Pressure and Variable Speed.
  - c. Complete Test.

Note.—C&D refers to Carpenter & Diederich's Experimental Engineering, edition of 1915. ASME is the Power Test Code of the American Society of Mechanical Engineers, procurable from the Secretary, 29 West 39th St., New York, at a cost of $1.60.

Numerals refer to articles, and are inclusive.

Notes to the Tests.—(A1) The head must be maintained constant during discharge by adjustment of the inlet valve. When conditions have become steady, put a suitable weight on the scale beam, and take the time with a stop watch the instant it rises. Add (W) pounds to the scale beam, and take the time when it rises again. The interval will be the time of flow. Compute values of (W) to make the runs about two minutes long, if possible.

Block up the orifice holder, which is not in use, with a blank to prevent leakage.

Start with a head of six feet, and make runs at one foot intervals down to one foot head. Conclude with a run with a six-inch head.

Plot values for the coefficient of discharge as ordinates, heads as abscissas, and draw curves for each orifice. Use one curve sheet for horizontal-plane runs, and another for vertical-plane runs.

(A2) Start the pump very slowly, with the return valve from the attic tank wide open. When the water begins to flow down, close the return valve very slowly until the tank gage shows value assigned by instructor—and then keep it there, by starting and stopping the pump as required. Vary the discharge by regulating water valve, and maintain the tank level with the pump. Great care must be taken to keep the gage within the limit of depth of the tank and so prevent overflow and consequent damage to the building.

If preferred, the experiment may be performed with city water, opening the condenser circulating valves for this purpose, and allowing the water to run to waste from the pit.

Zero reading for hook gage is to be obtained with a spirit level from sill of the notch to point of hook. Readings for hook gage are to be taken when the point of the hook visibly punctures the surface of the water. The adjustment should be made from below upward.

To determine the time of flow, use the method of timing the initial and final rise of the scale beam under two arbitrary loads. For convenience, the scale with tub may be wheeled under the jet just before beginning the run.

Plot values of the coefficient of discharge as ordinates, heads as abscissas, and draw smooth curves to average the positions of the points.

(A3a) First level the pipe with a spirit level. Connect hose and manometer. Open both valves on pipe wide. To reduce back pressure on manometer, the water should discharge from the bibb directly into the tub. Open main valve slowly to obtain maximum difference on manometer. Open bleeders at top of manometer, a little at a time, until the tube above the mercury is filled with water, and all air bubbles have escaped. Now start run by putting empty tub under discharge valve, and immediately read manometer. Watch the manometer during the run. If it varies materially, stop run and repeat. Make runs one minute long. On account of the oscillatory waves induced in the pipe lines by the boiler-feed pump at the power house, it may be necessary to partially throttle the manometer lines with pinch- cocks.

Partly close admission valve to get a smaller manometer difference. Always work from larger to smaller differences.

The actual internal diameter of pipe is to be taken from a table of pipe sizes. Measure it as a check.

Plot values of the coefficient of friction as ordinates, velocities as abscissas, and draw smooth curves giving the values of (f) for each pipe throughout the whole range of velocities.

(A3b) The values of the coefficient (f) are to be taken from the curve sheet for the preceding experiment. Measure very carefully the length of straight pipe, measuring from shoulder to shoulder of the elbows.

Plot values of (k) as ordinates and velocities as abscissas, and draw smooth curves showing the value of the elbow coefficient for each size of elbow.

(A4a) See that the by-pass valve is shut, and open valve on main line slowly, or until the maximum reading (do not pass this reading) of the manometer is reached. If the valve is opened too wide, the mercury will be thrown out of the manometer. When conditions of flow are steady, read the manometer and see that this reading does not change while the discharge is being weighed. In determining discharge, use the method of timing the rise of the scale beam under initial and final loads. Record initial load, and use a final load that will make the run about one minute, (for high velocities, this time will have to be decreased).

Make a number of runs, covering the whole range of the manometer scale, and decreasing the scale intervals as the scale reading decreases. The desired manometer reading may be obtained by regulating the flow through the main valve, or for close adjustment, by opening or closing the small by-pass valve which in that case would act as a fine adjustment.

Keep the water level in the attic tank at a value to be assigned by the instructor; be very careful to prevent overflow of the tank.

Plot the meter coefficient against velocity, and draw a curve showing the value of this coefficient for any velocity within the range.

(A4b) Cut off the valve on the main line, and regulate the flow through the by-pass valve to give a discharge rate, as shown by the meter, of two cubic feet per minute (the maximum capacity.) After the conditions of flow have become settled, continue at this rate for approximately ten minutes. To avoid the estimation of fractional values on the small dial, operate the meter from one definite mark to another.

Weigh the water discharged per minute several times during this interval. Use the method previously given of timing the rise of the scale beam under initial and final loads.

Repeat the process of a number of times, varying the adjustment of the by-pass valve to cover the whole range of the meter, from maximum to minimum flow.

Sketch the piston of the piston meter, showing its relation to intake and outlet ports. Plot values for correction factor as ordinates, indicated discharge as abscissas, and draw curve showing the value of the correction factor for any reading of the meter.

(B1) Calibrate the steam-flow meter and the water gage of the separating calorimeter, and verify Napier's Law. Calibrate the discharge gage at ten pound intervals and the water gage at one point.

Disassemble the calorimeter and examine its construction. Measure the diameter of the discharge orifice|. Reassemble and attach to the steam main. Discharge steam from calorimeter into a tub filled with cold water. See that the water does not reach the boiling point, to avoid evaporation losses.

To calibrate the water gage, fill the calorimeter with water and discharge to the point marked '20' on the scale. Continue to discharge to zero, catching the discharge in a graduate. Take its temperature. From the tables for density of water, transform this result into pounds at 300°F.

Why should the water gage be calibrated at 300°F for our use? With the discharge from calorimeter at the bottom of the tub of water, find the lowest value of the steam pressure for which Napier's Law holds.

(B2) Remove the steam chest cover from the steam end of the duplex pump. Unfasten the valve rod at its driving end, and screw the rod out of the valve block, so that the valve can be removed for examination. There are two ports at each end of the cylinder. The outer ones are the inlet ports, the inner ones the exhaust ports. If the same port were used for both inlet and exhaust, as in the case of the steam engine, the piston would strike the cylinder head on every stroke. By locating the exhaust port a little distance from the end of the cylinder, the piston covers it, and traps steam for a recoil cushion at the end of its stroke.

Sketch the steam and water ends of the pump, showing valve arrangements. To set the steam valves, pry the pistons into mid-position, place the steam valve in mid-position, and screw the valve stem into the valve block just far enough to give equal clearance between the block and each driving lug. This clearance allows the steam valve to remain open until the block closes up and strikes the lug, or for nearly the whole stroke.

Try the pump after reassembling. If it "limps," correct valve setting slightly until it runs with even strokes.

(B3a) Fill the pit with water and start the pump at 60 r. p. m. to be maintained throughout the test. Connect the exhaust discharge to the condenser, and arrange to weigh condensate at regular intervals. Attach the separating calorimeter, and take readings for quality of steam. Make a series of at least four twenty-minute tests, varying the discharge pressure between tests by throttling with the discharge valve. Oscillation of the pressure-gage hand may be prevented by nearly closing the small valve to the gage.

Record and report on the following items from Table 13, Power Test Code of the American Society of Mechanical Engineers: 1, 2, 4, 7, 8, 9, 10, 12, 12a, 13a, 14, 15, 18, 20, 21, 23, 24, 25, 26, 28, and 30.

Plot the steam consumption against the delivery pressure,

(B3b) Open the pump discharge valve wide, and regulate the overflow valve from the attic tank to maintain a constant head in the tank of value as assigned. Attach the hook gage and take readings of the head over the rectangular weir. Make at least four twenty-minute tests, varying the speed between tests. Record and report on the following items from Table 13: 1, 2, 3, 4, 7, 8, 15, 16a, 17, 17a, 22, 22a, 22b, 27, 30, 30a, 30b, 32, 35, 35b. Plot delivery and slip against speed.

(B3c) Make a single complete one-hour test of the pump, recording and reporting on all of the items of (B3a) and (B3b) and the following additional items: 37, 37b, 38a, 39, and 40.

CHAPTER V.

INTRODUCTORY POWER TESTING.

Power Testing Instruments.—Among the auxiliary instruments commonly employed in power testing are gages, thermometers, the throttling calorimeter, indicators of various kinds, and the polar planimeter used in finding the areas of the indicator cards. These instruments, with the exception of the calorimeter, which may be accepted as accurate, should be checked against reliable standards, and this is the primary object of the calibration tests to be made upon them. The results should be embodied in a special report, showing in convenient form the error, if any, of each of the laboratory instruments which are to be employed in the investigations to follow—the word "investigation" is not used with any idea of dignifying these routine commercial tests, but simply to indicate laboratory units, each to be covered by a separate, single report. The secondary object, of course, is to give that minimum of familiarity with the apparatus which is required in advance of its use in a test.

It is not the intention, generally speaking, to utilize the results of instrument calibration in tedious corrections. If the errors are found to be small and not likely to affect the final result within the expected degree of accuracy, the instrument is accepted as satisfactory, and no corrections need be made. Instruments which show large and irregular errors had better be corrected if possible, or if not, discarded. But the important thing is to know the condition of the testing equipment; otherwise no confidence can be placed in the results obtained with it. To clench the matter, the calibration of every instrument is frequently repeated, in practice, at the end of the test to discover whether any change has taken place during its use.

Boiler Testing.—The power which a boiler will develop is largely a matter of how much coal can be burned on the grates. Modern installations, with stokers using forced draft, easily reach several times the boiler's rated capacity. Boiler tests are usually made, therefore, not to find the capacity but the effciency of combustion. More properly, it is a furnace rather than a boiler test, since the boiler itself has very little effect on economy.

This efficiency may be expressed as a ratio of the steam produced to the coal burned. The measurement of the coal consumed is effected in the simplest and most direct manner by weighing the coal as it is fired. The steam produced might be metered, but it is better practice to weigh or meter the water pumped to the boiler as feed water. Since the water level in the boiler remains unchanged, this must equal in weight the steam passing out through the main.

The result, expressed as a percentage of perfect performance, will lie in the majority of cases between fifty and eighty per cent. A complete boiler test seeks to measure not only the heat from one pound of coal which goes to make steam, but to separate and determine those remaining parts which make up the avoidable or unavoidable losses. The sum total should then be one hundred per cent, and the nearer this total is to one hundred per cent, the greater the probability that the test has been accurately performed.

Flue Gas Analysis.—By far the largest of these losses is in the sensible heat carried up the chimney by the flue gas. The temperature of these gases at the base of the stack varies from perhaps 1000°F down to a minimum which is fixed by the temperature of the steam and water in the boiler. The best efficiency demands a low temperature, in the neighborhood of 500°F, but the magnitude of the loss depends primarily not on the temperature, but on the quantity of flue gas.

A certain amount of air is required to furnish oxygen for combustion, but frequently more air is supplied than is needed, and this air is cold relative to the glowing fire, chilling it like a stream of water. The excess air, unused and unchanged, has been heated to the tempearture of the flue at the expense of the fire and this heat passes out at the top of the chimney, a total and often a very large loss.

The problem of high boiler efficiency is the problem of reducing excess air to the lowest point at which complete combustion is assured. Its amount is exactly indicated by the percentage of unused oxygen in the flue gas. The main constituents of flue gas are carbon dioxid, the product of perfect combustion; free oxygen from air supplied in excess of that required for combustion; and small quantities of carbon monoxid, when combustion is incomplete. The Orsat apparatus tests the gas for each of these constituents in turn, and gives the percentage present.

When burning coal whose combustible is mainly carbon such as anthracite, semibituminous, and bituminous coal of high rank, the sum of the oxygen and carbon dioxid percentages is nearly twenty-one per cent. For twenty-one per cent of the air supplied is oxygen, and of that oxygen whatever part is used in burning carbon is replaced by an equal volume of carbon dioxid. As a result, for rough work, the carbon dioxid analysis—by subtraction from twenty-one per cent—gives the oxygen percentage; and since this is much the easier and quicker analysis of the two to make, the majority of boiler efficiency apparatus is based on the simple CO_2 test.

The Draft Gage.—Excess air, whose presence is discovered by the Orsat analysis, comes in greatest quantities through the open or bare spaces which careless firing or stoker management have left on the grate bars. The draft gage shows the difference in the pressures above and below the grates which carry the fuel bed. Briefly, it gives the pressure in inches of water required to force air against friction through the fuel bed. Different kinds of coal, thicknesses of fire, and rates of fuel consumption require different amounts of draft, and the instrument is valuable in fixing the proper damper opening, upon which the draft depends. But it is most valuable because it promptly shows the thinning or opening up of the fire bed as it burns away from its proper uniform thickness. For if the fire burns away at one spot on the grate, leaving it bare, the resistance of the fire bed diminishes, since the friction of flow through the grate openings is much less than through a compact bed of fuel; the draft reading drops; the extra and unnecessary air starts to rush through this hole to cool the fire. By observing a draft gage, the fireman is able to correct a poor fire as soon as it occurs and to maintain a continuous high efficiency.

Steam Engine Testing.—Steam engines are tested not only for maximum power, governing, etc., but also for their mechanical and thermal efficiencies. Mechanical efficiency is the ratio of the horse-power available at the shaft to that produced within the cylinder, as determined by means of indicator, and this problem is one in the use of the indicator and the evaluation of indicator cards with the planimeter. The result should lie between seventy-five and ninety-five per cent, and depends upon the mechanical construction and lubrication of the engine.

Thermal efficiency, which fixes directly the economy of operation, is the ratio of the power output to the equivalent power input in the form of heat in the steam used. The amount of steam used per brake horse power delivered can be found by weighing the feed water, if the boiler supplies a single engine, or by condensing the exhaust in a surface condenser, and weighing the condensate.

The Second Law of Thermodynamics, which fixes the maximum theoretical efficiency of every kind of heat engine, shows that only a small proportion of the heat supplied in the steam can be used in the production of power. In every case, the great part of such heat supplied is rejected in the hot steam of the exhaust. Notice, however, that this loss is not due to the sensible heat of the exhaust,—for the steam may be expanded down to a temperature of 60°F without materially reducing it —but to the fact that it must be exhausted as steam, which regardless of temperature still holds to most of the heat received in the boiler from the fuel.

The number of pounds of steam required to produce one horse-power is to be found by test. The original heat stored by the boiler in each pound may be found from the steam tables, proper correction being made for the quality of the steam, or the proportion of condensed vapour as determined by the calorimeter test. The remaining question is, What credit, if any, should be given for the heat of the exhaust? Obviously, the engine could not be credited properly with the whole heat content of the exhaust steam, since it has already "skimmed off" the "cream" of that heat available for conversion into power; and the exhaust steam, still nearly as fit for any process requiring heat and not power as the original live steam, can no longer be used in an engine. By convention, the only credit to be made for the exhaust is that for the heat in the condensed liquid as it flows from the condenser, it being assumed that this condensate could be returned to the boiler, and the heat in an equal quantity of feed water saved.

Thermal efficiencies, therefore, are invariably low—in some cases as low as two per cent—and this shows very clearly the advantage possessed by any plant which can utilize fully its engine or turbine exhaust in heating or process work.

The Indicator has a number of valuable possibilities in addition to finding the indicated or cylinder horse-power of the engine. Among these are the information which it gives with regard to valve setting, cylinder leakage, etc., and the ability to find from an indicator card the approximate steam consumption of large engines without surface condensers.

ENGRG. 690—INTRODUCTORY POWER TESTING.

(A) Standardization of Instruments.	(References.)
1. Gage Testing.	C&D 92; 95; 97. ASME 9g.
2. Adjustment of Gages.	C&D 96.
*3. Valve Setting.	
4. Calibration of Thermometers.	C&D 102; 107. ASME 9h.
5. Calibration of the Planimeter.	C&D 21-24; 31.
*6. Throttling Calorimeter.	C&D 304-307.
7. Calibration of the Indicator.	C&D 316-317; 320-322. C&D 325; 329-330.
§8 Flue Gas Analysis.	C&D 274-278; 280; 284-286.
(B) An Investigation of the Performance of a Steam Boiler.	
1. Sketch of Boiler and Setting.	
2. Boiler Test (12 hours).	C&D pgs. 708, 709. ASME 34-61.
3. Coal Analysis.	ASME 24; 26. ASME 272-276.
(C) An Investigation of the Characteristics of a Steam Engine.	
1. Mechanical Efficiency.	C&D 341-348.
2. Thermal Efficiency.	ASME App 18-19; 27. ASME 62-78.
3. Complete Test.	ASME App 28. ASME App 33.

Note.—C&D refers to Carpenter & Diederich's Experimental Engineering, 1915 edition; ASME is the Power Test Code of the American Society of Mechanical Engineers, procurable from the Secretary, 29 West 39th St., New York. (Price $1.60).

*Report under (C).

§Report under (B).

Notes to the Tests.—(A1) Use the Crosby dead-weight gage tester. Calibrate several gages. Read carefully the instructions inside the tester box.

Make a sketch of the apparatus. Measure the diameter of the piston at ten points and average them. Calculate the piston area and find the percentage of error of the apparatus, assumed frictionless. Weigh piston and disk. Why is it necessary to spin disk slowly when taking a reading? Plot true values as ordinates and gage readings as abscissas and draw curves for each gage. Draw a reference line through the origin at forty-five degrees.

(A2) Use the S&B oil-pump tester. Remove the cover of the gage, and take off the gage hand with the small jack provided for the purpose. Examine and sketch the construction of the gage. Why is the gage spring elliptical in section? What is the purpose of the small hair spring? Loosen the two screws which hold attached the adjustable lever and change its length. Reassemble the gage and test it; then attempt to readjust it to read correctly by moving the lever in or out until the proper point is reached. Notice that any gage which is found to be in error by the same amount at all points may be readily corrected by simply removing the hand and replacing it at the correct position. It is only when an error in proportionality exists, that it is necessary to change the length of the gage lever as described.

(A3) Adjust the slide valve on the Ball engine in the laboratory. Set the valve so that the lead is the same at both ends of the stroke.

Remove the cover of the valve chest. Mark with one of the trammels the position of the valve rod when the valve is about to open for each end. Find the dead center for each end by the method of trammels, and mark its position similarly on the valve rod.

The method of trammels consists in marking with a scribe corresponding points on crosshead and guide when the flywheel is approximately 30° from one of its dead centers. Mark this position on the fly-wheel with a trammel; then pass dead center and rotate backward toward it until the crosshead-guide marks again register. Mark also this position on the flywheel, and bisect the distance between the marks on the flywheel with a pair of dividers. Rotate the flywheel until the trammel reaches the bisection point, and the engine is on dead center.

Note that the leads having been equalized, their amount can only be altered by shifting the eccentric on the shaft. This is the function of the governor.

Draw an accurate sketch to scale of the valve and ports, and a Zeuner diagram showing the points at which the various events occur in the stroke.

Why is it necessary to find dead centers exactly? How is the effect of lost motion avoided in the method of trammels? What type of slide valve is this?

(A4) Use thermometer wells in steam tank, a tested gage, and steam tables. Read the thermometer, correct for stem exposure, read the gage and find the true temperature from the steam tables. Read the barometer.

Calibrate two thermometers at intervals of about five pounds by gage. Record depth of immersion.

Fill the wells with cylinder oil, being very careful not to get any water into them. Attach tested gage. Obtain the desired pressure by regulating the admission and exhaust valves. The more delicate adjustment is with the exhaust valve. Hold the gage steady for at least five minutes before reading the thermometers. Tap the gage to eliminate friction.

Plot true temperatures as ordinates and thermometer readings corrected for stem exposure as abscissas. Plot also stem exposure corrections as abscissas.

In very accurate work, how may the stem correction be avoided?

(A5) Use the Amsler planimeter, dividers, scale and a smooth sheet of drawing paper. Test the planimeter for four sizes of circles, two having the pole point of the instrument outside their areas. Make five readings on each circle, and compute the average percentage of error for each.

Draw circles with dividers, and measure the diameter to 0.01 inch. Traverse circles very carefully. Do not set the wheel to zero, but record reading at start and finish. Set the adjustable arm so that the wheel will read in square inches.

When the tracing point is traveling on the zero circle, the wheel does not rotate. Find its approximate radius by this test. Preferably, make one of the two large circles smaller and one larger than the zero circle. Note very carefully when the pole point is within the area to be measured whether the wheel is running forward or backward. The direction of rotation changes sign at the zero circle.

Measure the dimensions of the instrument and calculate from them the radius of the zero circle and instrument constant.

Deduce a formula for setting the adjustable arm of the planimeter so that the wheel will read the horse power directly from an indicator diagram.

(A6) Find the quality of the steam above and below the steam engine separator, and consequently the effciency of the separator. Connect the manometer when in use below the separator, but when in use above assume the back pressure to be 15 lb. per sq. in. Take readings at two-minute intervals.

First insert the sampling tube clear across the steam main. Pack the lock nut and srcew it up tight. Connect valve and thermometer cup to the sampling tube, and the calorimeter to the former. Then set up the manometer, and join it to the calorimeter by a rubber tube. Fill the manometer with mercury, and the two thermometer cups with cylinder oil. Let the calorimeter get thoroughly hot before beginning the test. The barometer must be read. Drain the separator before testing the quality of steam below it. From the mean values for quality, comment on the performance of the separator. How would you proceed if the results for quality were greater than unity? At the steam pressure in the main, calculate the greatest percentage of moisture which this calorimeter can show.

(A7) Use the steam tank with tested gage, two indicators, and a scale reading to 0.01 inch. Calibrate two indicators for two springs, each, at ten pound intervals. Springs to be calibrated in indicators to which they belong.

Study the assembly of the indicator. Select a spring and put it in place. Oil the piston of the instrument with cylinder oil.

Rule two vertical lines on an indicator card. Attach the indicator, put card in place and admit steam to heat thoroughly. Close the cock, and draw atmospheric line. Slowly raise the pressure. At the instant the gage hand crosses the desired reading, going upward, draw the line to the left from the right-hand vertical. Repeat readings with the hand going downward, drawing lines to the right from the left-hand vertical. The pencil must be sharp, and the pressure against the card the lightest that will leave a visible mark.

Disassemble the indicator, remove spring, and wipe all parts with a little oily waste.

Sketch one of the indicators and describe the method of changing its springs.

(A8) Set up the Orsat apparatus on a table adjacent to the boiler setting. Attach the rubber tubing of the Orsat to the cock of the flue-gas line. See that the pipettes are filled with the proper reagents, and that the level of the reagent stands in each case at the mark on the glass tube above the pipette. The jacket surrounding the measuring burette should be filled with water to insure a uniform temperature for the gas during measurement. Fill the leveling bottle with water. A few drops of red ink added to the water give it color and make the readings easier to see.

The first step in making the analysis is to clear the line. This should be done by using the water in the leveling bottle as a piston, alternately drawing in fresh volumes of flue gas as the level in the burrette falls, and expelling them to the atmosphere by proper manipulation of the cocks when the water level in the burette is forced up by raising the bottle. This process should be repeated perhaps ten times to insure a strictly fresh sample.

On the last of these inspirations of flue gas, trap a sample in the apparatus by holding the rubber tubing from the bottle in the fingers of the left hand, closing it off just as the water level in the burette falls below the zero mark. Then close the cock to the gas line, and bring the level of the water in the bottle to the level of the water in the burrette, against which read the initial volume, which should be in the neighborhood of zero.

The analysis for carbon dioxid is to be performed by opening the cock communicating with the pipette which contains a solution of potassium hydroxid, and passing the whole volume of gas into this pipette by raising the water level in the burette until it has been entirely expelled. The gas sample should then be passed back again into the burette, and the whole process repeated several times, or until absorption of carbon dioxid by the caustic solution is probably complete.

On passing the gas back into the burette for the last time, draw the solution in the pipette very carefully up to the mark on the glass tube above it. Hold the rubber tubing joining the leveling bottle to the burette, as before, in the fingers of the left hand, pinching it off slowly as the solution level approaches the mark on the capillary tube. If this part of the operation is not done with great care, the solution will be drawn up into the main capillary and over into the burette, and the analysis will be spoiled. If this should accidentally happen, stop at once, empty out the water in the burette and leveling bottle, and refill. Close the cock to the pipette, bring the level of the water in the levelling bottle to the level of the water in the burette, and read against this level the volume of carbon dioxid absorbed. If the initial reading was zero, then this reading gives the percentage of carbon dioxid.

Pass the gas back once more into the pipette, return it to the burette, and read again as a check against the first result. If the two are in agreement, this analysis is complete. Otherwise, continue until two readings are in agreement.

The analysis for oxygen is to be performed after the carbon dioxid analysis, and in precisely the same manner, except that much more time will be required. The reading now will give the total of carbon dioxid and oxygen, and the oxygen may be found by subtraction.

The instrument reading, or the total of the carbon dioxid and oxygen in the flue gas, corrected for the zero or initial reading, should lie between 18 and 21 per cent, depending upon how much the theoretical total of 21 per cent has been reduced by the combustion of hydrogen in the fuel.

The carbon monoxid analysis must be made after the removal of both carbon dioxid and oxygen, but in the same manner. This analysis requires still more time, and at least twenty minutes should be allowed for it. Traces of carbon monoxid, running as high as 0.5 per cent, are frequently present in flue gas containing large excess of oxygen. But unless the oxygen excess is very small, an analysis showing several per cent of carbon monoxid is presumably in error. Note particularly that when using an acid solution of cuprous chloride, before the final reading the sample must be passed back once through the caustic solution to remove the acid vapour.

Take the temperature at a point in the flue close to the sampling tube. A nitrogen-filled mercury thermometer may be used for this purpose, or a pyrometer. Calculate from the flue gas analysis the percentage of excess air, and the sensible heat lost in the dry flue gas per pound of carbon burned.

(B1) Examine and sketch to scale the boiler, showing the number, size and arrangement of tubes; the furnace and setting, showing the grates, the bridge wall, and the method of baffling, if any; and the passage followed by the products of combustion from the fire to the stack.

(B2) Run a 12 hour test on one of the boilers of the University power plant, starting at twelve o'clock noon, and continuing until midnight. All the preparations for the test should have been completed on the preceding day.

Weigh all coal fired to the boiler under test in 100 lb. drafts. A platform scale may be used for this purpose. Take a small sample from each draft, previous to weighing, for the total coal sample, which should aggregate 500 lb. at the close of the test.

See that the boiler under test is being supplied with water from no other source than the feed pump selected. This feed pump should take its suction from a tight barrel resting on a platform scale. Fill the barrel with water to a depth sufficient to submerge the suction line, and weigh water and barrel, setting the large poise permanently in position. Add 400 lb. weight to the hanger and continue to fill barrel until the beam rises. Then start the pump and continue in operation until the beam falls. Correct the balance when filling and emptying with the small poise weight to take care of any excess added or withdrawn after the rise or fall of the beam.

Plot a graphical log during the progress of the test. See Appendix 23, Power Test Code of the American Society of Mechanical Engineers.

Take readings at fifteen-minute intervals of the draft gage, steam pressure., flue temperature, feed temperature, humidity, carbon dioxid, etc. Take occasional readings for oxygen and carbon monoxid. Attachment for the draft gage should be made through closed doors over the plain grates. Flue gas samples and flue temperatures are to be taken at a point in the uptake from the boiler under test. The steam pressure gage must be tested.

The ash pit is to be cleaned at the beginning of the test. Clean it at the end of every hour, and weigh the ash. Take a small sample of it for the ash analysis.

The percentage of moisture in the steam may be found by bleeding the steam separator, if there is one on the main, the bleeder discharging into a tub of cold water. A throttling calorimeter should be located just beyond the separator, to find the quality of the steam leaving the separator.

Study carefully Table 7 of the Power Test Code, and be prepared to record and report on all of the items and subitems therein contained with the following omissions: 14c, 15, 15a, 15b, 15d, 22B, 22C, 22Da, 49, 49, 49a, 51d, 52e, 53c, 53d, 53e, 54d, & 54e.

With regard to item 53, the ultimate analysis of coal, this is to be computed from the proximate analysis by the method given Carpenter & Diederich's Experimental Engineering, article 270.

(B3) The sample of coal as taken at the time of making the boiler test is to be reduced according to the standard method as given in the course on Fuel Testing, and the proximate analysis and heating value determined. Check analysis should be made, part of the squad working on the proximate analysis, while part makes the heating-value determination; and then exchanging duties when making the check. The sample of ash, reduced in a manner similar to that employed for coal, should then be tested for volatile matter, total combustile, and ash. The method is the same as that used for coal. Compute the ultimate analysis from the proximate for the coal.

(C1) Place the prony brake in position on the flywheel of the steam engine, its lever arm resting on the block supported by a platform scale. It is imperative that one man should be detailed to watch the knife-edge contact between the brake and block when the engine is running, as the knife-edge has a tendency to work off the block. Oil the surface of the flywheel.

Obtain the tare of the brake by rotating the fly-wheel first forward and then backward, by hand, the tare being one-half of the sum of the scale readings under these conditions. Calculate the gross weight on the scale to give 5, 10, 15, and 20 brake horse power, and make twenty-minute runs with each of these loads, finishing with a no-load run.

Attach and connect one of the indicators and prepare to take indicator cards as rapidly as possible. Take a card under load and examine it to see whether the valve setting is correct. If not, correct it until the card shows equal work areas at each end. Preserve sample indicator cards from each run, to be pasted on sheets of full-sized paper and included in the final report on the steam engine.

As usual, the squad will be divided into parties of two men, each, and each party will be assigned to a duty at the beginning of the test. These duties might be the recording table; brake regulation and speed counter; and the indicator. At regular intervals, and under the direction of the squad captain, one man from each station should progress to the next station in a prearranged order, leaving one man at the station already familiar with its work to instruct the newcomer.

Study Table 9 of the Power Test Code, and be prepared to record and report on the following items: 1, 2, 3, 4, 5, 6, 7, 7a, 8, 9, 11, 12, 13, 14, 31, 32, 33, 34, 37b, 37c, 37e, 37f, 37g, 37h, 37i, 38, 39, 40, 41, 42, 42a, 42b, & 55. Figure item 8 from the cards.

A computing period will be assigned at which the entire squad will have an opportunity to work up the necessary data from the indicator cards, planimeters being furnished for the purpose.

(C2) Make brief runs at the same brake horse-powers as given for (C1). The indicator need not be used. Connect the engine exhaust to the condenser, and start the condenser. The runs may be made either condensing or non-condensing. In the latter case, although the exhaust passes to the condenser, the vacuum-breaking valve is opened sufficiently to reduce the vacuum to within a few inches of atmosphere, and the effect is the same as if the engine were exhausting against atmospheric pressure. Do not break the vacuum completely, in this case, as the high temperature of the liquified steam from the condenser results in a partial revaporization as it meets the air.

Weigh the condensate at frequent intervals, throwing the three-way valve on the condenser discharge line to discharge the condensate into an extra tub during the process of weighing.

Plot the steam consumption against the brake horse-power during the progress of the test. The points should lie on a straight line.

Attach the throttling calorimeter and take readings on the quality of steam during the run.

Study Table 9 of the Power Test Code, and be prepared to record and report on the following items: 1, 2, 3, 4, 5, 11, 12, 13, 14, 18, 18a, 20, 21, 22, 24, 25, 26, 29, 30, 38, 41, 44, 48, 50, 51, 53, & 54.

(C3) Make a single complete test of an hour or more at about the maximum brake horse-power of the engine. Do not set this too high, or an accidental drop in steam pressure may make it impossible to continue the test. Record and report on all of the items of (C1) and (C2) and the following additional items: 4a, 4b, 21a, 21b, 29a, 30a, 30b, 30d, 36, 37a, 39a, 43, 45, 46, 47, 49.

In measuring the heat given to the condenser circulating water by the exhaust stream, it will be necessary to meter the circulating water. This can be conveniently effected by discharging the circulating water into the weir tank, and taking hook gage readings of the water level over the vertex of the triangular weir. The coefficient of the weir may be taken as 0.60.

As already described, a preliminary report should be submitted for each of these tests. This will consist in the main of the tabular items listed for the test.

A finished, professional report covering the three tests as a whole should present in each detailed standard tabular form the results of the single complete test; should exhibit by means of suitability drawn curve sheets the characteristic variations of economy and mechanical efficiency with the load; and should include sample indicator cards, pasted neatly by their upper corners to full-size sheets of paper. The written matter should, of course, be arranged according to the plan previously outlined for these reports. A sketch of the slide valve, prepared from the preliminary report for (A3), should be given; and also a discussion of the throttling calorimeter from the preliminary report for (A6).

CHAPTER VI.

ENGRG. 691—ADVANCED POWER TESTING.

(A) An Investigation of the Characteristics of a Gas Engine.	(References.)
1. Valve and Igniter Adjustment.	C&D 357; 381.
2. Mechanical Efficiency.	ASME 188-198.
3. Thermal Efficiency.	C&D 394-396. C&D 382.
4. Complete Test.	
(B) An Investigation of the Characteristics of a Steam Turbine.	
1. Turbine Assembly.	C&D 367-372.
2. Non-Condensing Test.	C&D 373-374. ASME 79-86.
3. Condensing Test.	
4. Guarantee Test.	C&D 376.
(C) An Investigation of the Characteristics of an Air Compressor (or Blower).	
The selection of the equipment and the tests to be made upon it will be left to the squad after consultation with the instructor.	C&D 402-424. ASME 100-105.

Note.—C&D refers to Carpenter & Diederich's Experimental Engineering, edition of 1915. ASME is the Power Test Code of the American Society of Mechanical Engineers.

ADVANCED POWER TESTING.

The tests given in this course, a continuation of Engrg. 690, are similar in character and scope to the test of a steam engine, —E690—(C3). The use of the indicator is somewhat more complicated in the case of the gas engine, and somewhat simpler in the case of the air compressor than in steam engine practice; and it is dispensed with entirely in turbine testing.

Notes to the Tests.—(A1) Attach the gas-engine indicator, and be sure that the stop on the indicator piston rod is in place. Gas engine cylinders are liable to sudden excessive pressures, which will injure the indicator unless a safety stop is used.

Take cards with various adjustments of the igniter position, and determine the proper running position for the igniter to give a vertical ignition line.

Test the valve operations by taking a card with a very light spring (be sure to use a stop). The ignition should be momentarily cut off when taking this card.

(A2) Find the initial brake reading by balancing the brake on an improvised knife-edge, supporting the lever arm horizontally by means of a scale or balance. Note that this reading is to be added to the weight of the hanger and weights in computing the brake horse-power. Calculate the proper loads for the brake for two, four, six, eight, and ten brake horse-power, and make runs for each of these loads, finishing with a no-load run. It will be necessary to keep the channel in the brake pulley filled with water.

The determination of indicated horse-power for a gas engine controlled by a hit-and-miss governor is more difficult than it is for any steam engine. The governor throws the fuel admission valve momentarily out of operation, and the engine scavenges with pure air. When the speed drops and the governor restores the fuel admission valve to operation, the first explosion is weak, the succeeding ones increasing promptly to the maximum for continuous operation. It is, therefore, necessary to hold the pencil of the indicator against the card for precisely the interval between cutouts, and to average the areas of the succession of diagrams on each card.

Prepare to record and report on the following items from Table 20 of the Power Test Code: 1, 4, 5, 6, 6c, 7, 8, 9, 35a, 35b, 35c, 35d, 36, 37, 38, 39, 40, 41, 41a, & 42. Submit a sketch showing the fuel supply system from the tank to the cylinder. Include sample indicator cards.

Difficulty in the operation of this engine is frequently due to partial failure of the gasoline pump, which should then be repacked. A rather heavy cylinder oil should be used.

(A3) Arrange to take the fuel supply from a jar or bottle resting on a small platform scale. Make brief runs, using the same loads as those given for (A2). The indicator need not be used. Record and report on the following items from Table 20: 1, 7, 8, 9, 12, 16, 17, 20, 37, 40, 44, 46, 48, 49.

If the fuel used is commercial gasoline, its heating value may be taken as = 18,320 + 40 (Bé.—10) B. t. u. per lb. The specific gravity, expressed in degrees Baumé. (Bé.) may be found with a hydrometer.

(A4) Make one single test of one hour or more at about the maximum load which the engine will safely carry, recording and reporting on all the items of (A2) and A3) with the following additions: 2, 3, 3a, 3b, 3c, 3d, 3e, 4a, 11a, 11b, 15, 19, 38a, 43, 47, 50a, 50b, 50c, 51. The heat of the exhaust (item 50c) is to be found by difference.

To find the heat lost in the cooling water, the weight of cooling water supplied per minute must be measured, as well as the inlet and outlet temperatures. To weigh the cooling water, discharge it into a tub on a platform scale.

The final report covering the series of tests should include a sketch of the gasoline supply system from (A2); the standard tabular form for the single complete test; and the principal results from (A2) and (A3) plotted in the form of curves showing the variation of friction horse-power, mechanical efficiency, total fuel consumption, fuel consumption per brake horse-power-hour, thermal efficiency, etc., with the brake horse-power.

(B1) Remove the turbine casing by disconnecting the exhaust line, and withdraw the turbine rotor for examination. Study the design and construction of the blades and nozzles. What type of turbine is this? Why is the reduction gear necessary? Why is it necessary to have different nozzles for condensing and non-condensing use? How many nozzles should be open at a time? Sketch the construction of the turbine, showing shaft, rotor, blading and nozzles. Report on the following items from Table 11 of the Power Test Code: Items and sub-items one to six inclusive.

(B2) Wire the three-phase generator discharge to the water rheostat, and connect the turbine exhaust to the condenser. Make several short non-condensing runs, varying the electrical load between runs, and finish with a no-load run. Weigh the condensate discharged from the condenser, which is to be operated with a nominal vacuum of four or five inches of mercury to prevent reevaporation, and measure the electrical output of the generator. The power factor may be taken as equal to unity. The throttling calorimeter is to be attached below the separator, and the quality of steam determined. Remember that the calorimeter must always be thoroughly lagged by wrapping with waste and burlap or other heat insulator.

Prepare to record and report on the following items from Table 11 of the Power Test Code: 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 22, 23, 24, 25, 28, 38, 40, 41.

(B3) Exactly similar to (B2), except that the condenser is to be operated with the highest degree of vacuum obtainable with it, and the condensing nozzles on the turbine are to be used instead of the non-condensing nozzles. Note that a high vacuum can not be obtained unless all the various valve stems on the exhaust line are packed tight. The most trivial leakage will be sufficient to break the vacuum.

(B4) Make a single one-hour test, or longer, operating the condenser with high or low vacuum to give either a condensing or a non-condensing run, using the corresponding nozzles. Prepare to record and report on all the items of Table 11, with the following exceptions: 10a, 10b, 16. To find item 22a, the condenser circulating water, meter this water by discharging it into the weir tank as in E690-C3.

Reduce the operating conditions to standard guarantee conditions and compare the economy with the guarantee figure. Data for this, as well as for reducing electrical to brake horse-power, is on file in the office.

The final report should include a sketch of the turbine from

(B1); the standard tabular form showing the results of the single complete test; and the principal results of the short series of condensing and non-condensing tests plotted on curve sheets to exhibit the characteristic variations of economy—in its several methods of expression—with electrical output for the two conditions of operation.

(C) The choice of a blower or an air compressor for the final test will be left to the class, as well as the tests to be made.